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RESEARCH AND EDUCATION

Effect of different design of abutment and implant on stress distribution in 2 implants and peripheral bone: A finite element analysis study

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ABSTRACT

Statement of problem. How adjacent dental implants with different sizes, designs, and abutment connection shapes affect stress on the prosthetic structure is unclear.

Purpose. The purpose of this finite element analysis (FEA) study was to analyze stress distribution around bone and around 2 implants with different sizes, diameters, shapes, and loading directions placed next to each other in splinted and unsplinted prostheses.

Material and methods. On 3D FEA models representing the posterior right lateral segment of the mandible, 1 implant (Ø3.5×12 mm) and 1 implant (Ø5.5×8 mm) were placed adjacent. Three different contemporary implant models were created with different teeth, pitch, spiral numbers, and self-taping features, and different abutments for them were modeled in 3D. The implant-abutment connection was internal hexagonal (MIH), stepped conical (MSC), and internal conical (MIC). Vertical and oblique loads of 365 N for molar teeth and of 200 N for premolar teeth were applied as boundary conditions to the cusp ridges and grooves in a nonlinear FEA.

Results. The MIH implants resulted in improved stress conditions. According to the von Mises stresses occurring on the screw, abutment, and implant, especially under oblique loads, MIH was exposed to less stress than MSC, and MSC was exposed to less stress than MIC.

Conclusions. When a standard implant and a short implant were placed adjacent and splinted by crowns, the implants, abutments, and screws had unfavorable stress levels; therefore, adjacent splinted implants should be of similar size. The form of the implant-abutment junction is also an important factor affecting stress. (J Prosthet Dent 2021;126:664.e1-e9)

Dental implants of standard and short length are popular options for restoring esthetic and functional problems caused by tooth loss.[1-5] During functional movements, stresses on the implant-supported prosthesis are transmitted to the surrounding tissues through the implants.[6-10] Overload on implant-supported restorations can lead to bone resorption around the implants.[7] The ultimate tensile and compressive strengths of the cortical bone have been reported to be approximately 100 to 121 MPa and 167 to 173 MPa, respectively.[11] Although information is available regarding ultimate compressive and tensile strength, stress values that cause in vivo biological changes (absorption and remodeling) in the bone are lacking. Therefore, the main goal in implant-supported restorations should be to reduce stress values and provide even stress distribution.[8]

Among implants of the same diameter, short implants show increased stress-strain levels compared with those of standard length implants, so the splinting of short implants has been recommended to prevent overloading.[12] It has been noted that peri-implant marginal bone loss around nonsplinted implants is statistically equivalent to that observed with splinted implants[13] and that splinted prostheses can be used for short implants and nonsplinted prostheses can be used for regular implants.[14] A summary of selected studies on this subject is given in Table 1.

When the implant is placed in the posterior mandible, the state of the residual alveolar bone and the anatomy of the mandibular canal may require the placement of a standard-sized implant and an adjacent short implant.

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Clinical Implications

If implants of different lengths are placed close together, separate crowns should be made, and stress is reduced if the fit of the implant-abutment junction is optimized.

However, whether prosthetic restorations supported by implants of different sizes and diameters placed adjacent should be separate or splinted is unclear.[21,22] Thus, splinted and nonsplinted restoration designs can change stress levels in adjacent implants of different lengths and diameters. Although better stress distribution can be achieved with splinted restorations, a consensus on this issue is lacking.[16,17] Additionally, the implant, abutment, and restoration design can affect stress levels to the bone and implant.[18,23]

Noncylindrical abutments provide a more stable locking mechanism that reduces micromotion than cylindrical ones, but the tendency to concentrate at the corner points of stress increase the risk of microfracture and thus microcavity formation.[24] Internal hexagonal abutment connection systems produce a stable and more resistant restoration with less rotation and better force distribution.[11] Implant neck design and implant-abutment joint types affect peri-implant bone stresses and abutment micromotion.[15]

The design of the abutment connection has been reported to play an important role in the uniform transfer of occlusal stresses to the bone.[25] The implant-abutment connection design is among the important factors affecting the stress distribution on implant components. Stress has been reported to be transferred to the implant platform completely through the abutment, and an increase in the platform diameter has been reported to enable the stress to spread more evenly and to be distributed throughout the structure.[11,24] How the designs of implants, abutments, and restorations affect stress distribution in implants surrounding the bone is unclear. The authors are unaware of a study on whether the prosthetic superstructures of implants and abutments placed adjacent with different geometric designs, sizes, and diameters should be splinted or separated.

Stress distribution can be evaluated with finite element analysis (FEA), and studies have examined the effects of different abutment connection designs on implants.[12,26-28] Testing the stress and strain on the bone surrounding implants is difficult both in vitro and in vivo.[1,29] FEA can be used as an alternative to evaluate stress-related outcomes by modeling clinical conditions and to assess biomechanics in implant dentistry.[16,26]

The purpose of this 3D FEA study was to analyze the stress and strain distribution around short and standard implants in the posterior mandible with splinted and separate crowns. The null hypothesis was that prosthetic structures made with shorter and wider implants adjacent to a longer implant would not affect the stress on the surface of the longer implants and their components.

MATERIAL AND METHODS

Maximum principle elastic strain was compared on 2 implants of different diameter and length (Ø3.5×12 mm and Ø5.5×8 mm) with different spiral numbers and implant shapes and on different junction surfaces of the abutments. Implants designed differently in terms of pitch, self-tapping features, spiral numbers, and abutment connections were divided into 3 groups: internal hexagonal (MIH), stepped conical (MSC), and internal conical (MIC). To improve the relevance of the study, the implants and abutments of 3 different contemporary implant brands were modeled. The spiral numbers, pitch, self-tapping features, and abutment connections of these

Table 1. Summary of studies selected

Study and Year of Publication	Implants	Results
Hingsammer et al[12] 2019	Same diameter	Splinting of short implants recommended
Vigolo P et al[13] 2015	Same diameter	Multiple nonsplinted implants can be successfully included in many clinical situations.
Toniollo MB et al[14] 2017	Same diameter	Splinted prostheses can be used for short implants and nonsplinted prostheses can be used for regular implants.
Toniollo MB et al[16] 2017	Same diameter	Stress on bone around short implants reduced with splinted prostheses but opposite for standard long implants
Lemos CAA et al[17] 2018	Same diameter	Splinted crowns favor stress distribution by reducing stress in implant and abutment and cortical bone tissue. However, reductions in implant length did not influence stress distribution.
de Souza Batista VE[18] 2019	Review, different diameters	Splinted and nonsplinted implant restorations had similar marginal bone loss and prosthetic complications but that implant failure may be reduced in splinted restorations.
Amir R et al[19] 2017	Same diameter	Combination of short and standard implants has no biomechanical advantage, but splinting short implants is appropriate treatment plan.
Al Amri MD[20] 2017	Review, different diameters	No difference in crestal bone loss when adjacent implants restored splinted and nonsplinted.

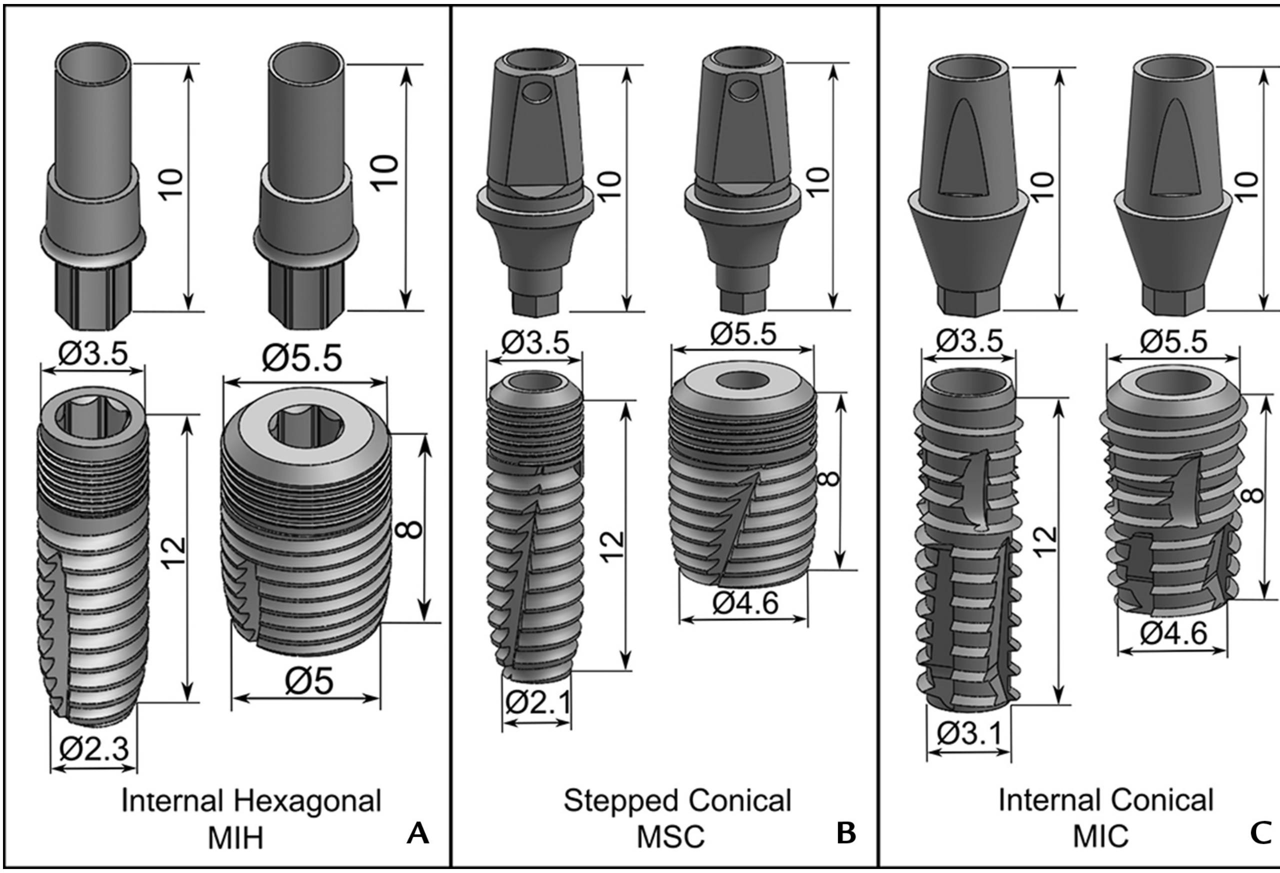

Figure 1. MIH, MSC, and MIC implant component properties and assembly models. MIC, model internal conical; MIH, model internal hexagonal; MSC, model stepped conical.

brands of implants are different and the abutment connections were not interchangeable. Therefore, keeping the implant pitch, spiral numbers, and shapes the same and only changing the abutment connections would not be realistic. In the current study, the effect of the abutment connections was examined by adhering to the original implant shapes.

A 3D FEA model for implants and bone was generated and then used for nonlinear deterministic analysis. A computer-aided design (CAD) model of implants and bone was created by using a software program (SolidWorks, v2019; Solidworks, Dassault Systems). Bone structure was modeled in 2 layers: cortical and trabecular bone. Before exporting the model to a finite element analysis software program (ANSYS FE; ANSYS, Inc), package, implants, abutments, screws, cements, and crowns were assembled in the mandible (Figs. 1 and 2) The FEA model consisted of SOLID72 10-node tetrahedral elements with a quadratic displacement behavior suitable for modeling irregular meshes, as in this study.

In total, 12 different FEA models were created and analyzed. The components were modeled as homogenous, linear elastic, and isotropic. Material properties are given in Table 2 and loading and boundary conditions in Figure 3. Metal-ceramic crowns were selected as the restoration type.[5] For the implant-abutment, abutment-screw, and screw-implant contacts, the friction contact definition with a friction coefficient of 0.3 was used.[23] All other contacts were considered rigidly bonded. The model assumes complete osseointegration of the implants. In the convergence models, the number of elements was approximately 525 000, and the number of nodes was 800 000. Two loading conditions were taken into account in a vertical direction and 30 degrees in an oblique horizontal direction in relation to the long axis of the implant, but only for the internal slope of the buccal cusps (200 N for premolar tooth and 365 N for molar tooth).[3,16,17,26] The maximum and minimum principal strain was used to evaluate the probability of failure at the implant-bone interface. The von Mises equivalent stresses (VMESs) were evaluated, which provided a convenient representation of the stress situation in metal implant components.

RESULTS

In the short and wide implant, all designs (MIH, MSC, MIC) had greater VMESs in the abutment, implant, and screw compared with those of the long and thin

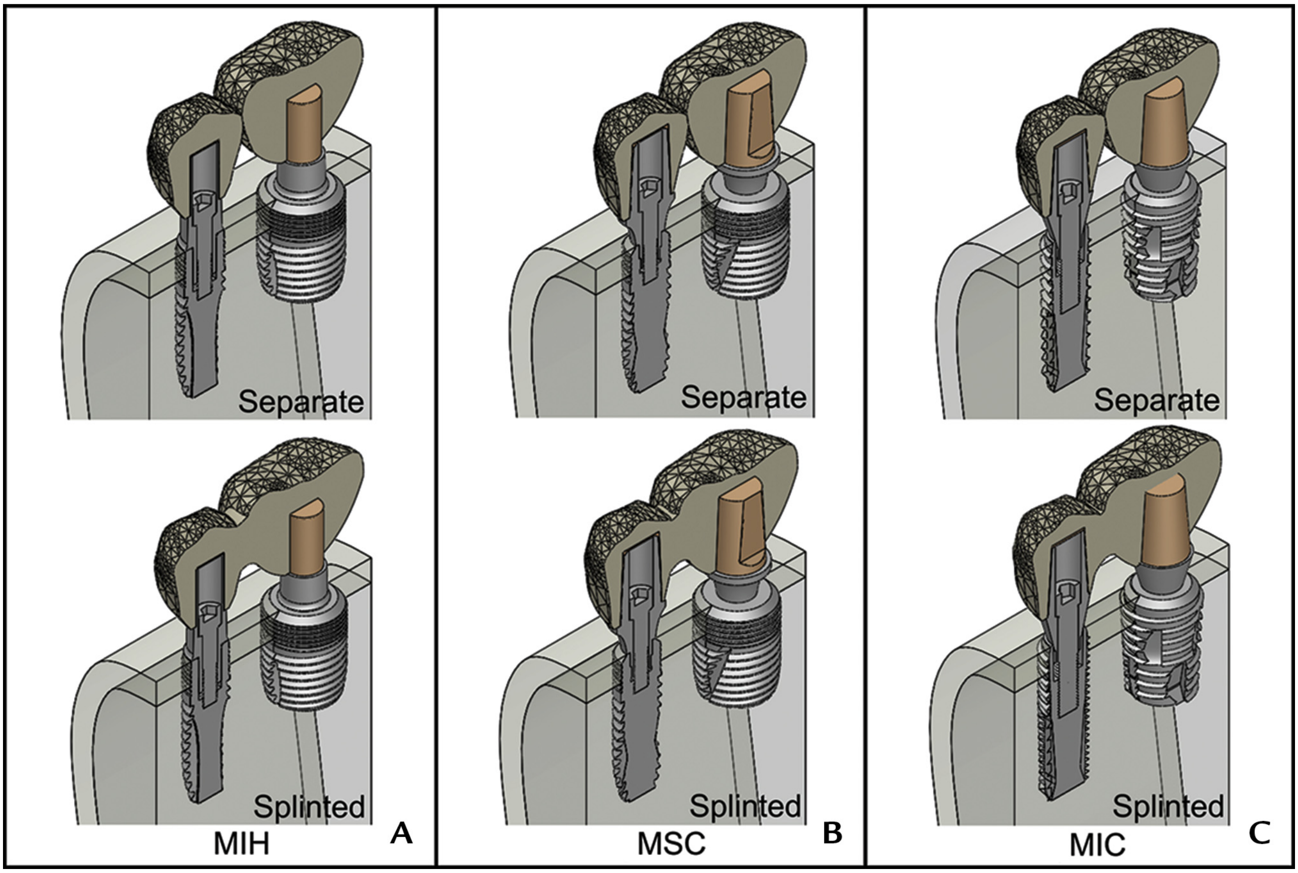

Figure 2. MIH, MSC, and MIC implant and prosthetic structure models. MIC, model internal conical; MIH, model internal hexagonal; MSC, model stepped conical.

Table 2. Material properties used in finite element models

Material	Elastic Modulus (MPa)	Poisson Ratio (ν)	Reference
Titanium (implant, abutment, and screw)	110 000	0.35	Sevimay et al[4]
Cortical bone	14 000	0.3	Wang et al[10]
Cancellous bone	1370	0.3	Chang et al[23]
Crown	140 000	0.28	Vaillancourt et al[5]
Cement	10 760	0.35	Tolidis et al[29]

implant. The main differences in different models were that, in the MIH, less stress was presented on the abutment, screw, and implants in vertical and oblique loading in splinted and separate crowns. While under the influence of oblique forces, the strain value increased, as the moment effect was seen more in splinted crowns for longer implants (Fig. 4). For the short implant, this was reversed in the MIH model. The stress on the short implant and screw decreased in the splinted prostheses only in the MIH model. Equivalent stress values occurring in all implant models and components (implant, abutment, and screw) under different loading conditions are given in Figure 4. The success of implant models and components can be determined by comparing the maximum equivalent stress values occurring in the same component (such as the screw). It can be seen from Figure 4 that these maximum values were not always obtained in the same implant model. However, under an oblique load, which is a more critical loading condition, the order in the stress values of all components is MIC>MSC>MIH. This result shows that the MIH model was the most successful model.

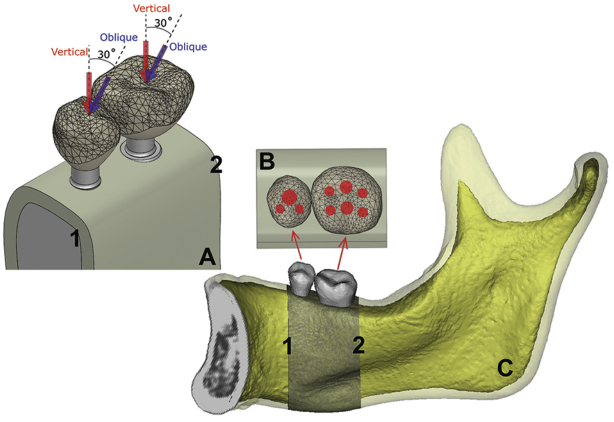

Figure 3. Loading and boundary conditions.

von Mises Stress (MPa)	MIH				MSC				MIC			
	Separate Crowns		Splinted Crowns		Separate Crowns		Splinted Crowns		Separate Crowns		Splinted Crowns	
	VL	OL	VL	OL	VL	OL	VL	OL	VL	OL	VL	OL
Abutment (SLI)	32	326	38	484	23	410	18	531	91	496	94	641
Abutment (SI)	71	465	62	539	35	537	28	565	86	586	94	715
SLI	20	222	19	283	15	348	26	355	25	363	28	484
SI	34	341	36	307	56	506	38	508	129	701	129	741
Screw (SLI)	2	35	1	62	9	97	1	166	113	125	248	182
Screw (SI)	1	98	1	57	2	110	1	150	151	195	240	217

Figure 4. von Mises stress (MPa) on abutment, implant, and screw under vertical and oblique loading for separate and splinted crowns. MIC, model internal conical; MIH, model internal hexagonal; MSC, model stepped conical, OL, occlusal loading; SI, short implant; SLI, standard long implant; VL, vertical loading.

While MIH and MSC implants had better stress distribution, the MIC implant was subjected to increased strain, which may lead to implant damage. Since the screw was also exposed to a stress proportional to the stress received by the abutment, the probability of screw damage was higher.

Under oblique loading in the MIH design (Fig. 5), the stresses on the screw were 50% less than with the MSC design, so the load on the screw was reduced. The perfect fit of the hexagonal geometric feature and concave curves on the junction surfaces of the abutment with the implant used in the MIH design explained the reduced stress at this implant-abutment junction. On examining the section to assess the strain values transmitted to the bone, high strains were found from oblique forces, suggesting that the MIH type implant should be more successful.

The MIH design gave the best results at the implant contact point with cortical and trabecular bone. In this evaluation, the minimum principal strain values were considered, as implants create compression stress on the bone. In the MIH design, the strain to the long implant was 40% less than in the MIC design. Less strain was also associated with the short implant in the MIH design, probably related to the implant abutment connection mechanism. The MIH design was better in terms of stress and strain in cortical and trabecular bone and at the implant junction. In the MIC design, the minimum principal elastic strain was observed at the junction surface of the implant and bone. The strain values transmitted to the bone were high under oblique forces, suggesting that MIH would be more successful than MSC.

DISCUSSION

Limitations of the present study include the assumptions that 100% osseointegration occurred between bone and implant, the simplistic boundary conditions in the model, and that no long-term bone changes occurred. However, the approximately 50% to 80% bone-implant contact commonly observed in implants is considered to be clinically successful.[9] Also, a study reported that different degrees of osseointegration had no major effects on implant stress distributions.[30]

The null hypothesis that splinted prosthetic structures with shorter and wider implants adjacent to longer implant prostheses would not affect the stress on the surface of the implants and their components was rejected. Whether the crowns were separate or splinted was not important according to the vertical loading condition. Under these conditions, the MIH implant was more successful than the others as seen by the cortical and cancellous bone cross-section strains (Fig. 6). For the boundary conditions under which the vertical load was applied to separate crowns, the order of the minimum principal strain values obtained from the models at the long implant-bone interface was MIH<MSC<MIC (Fig. 7A). The situation was similar for short implants, but strain values were higher for these implants. Since the bone-implant contact surface of the long implant was greater than that of the short implant, the increase in contact surfaces led to decreased strain values. Similar results were obtained under the boundary conditions where the vertical load was applied to the splinted crowns (Fig. 7B).

The geometric design of the implant and the abutment is also an important factor affecting the prosthetic superstructure, but studies investigating this situation are lacking. Significantly less stress on the implant neck has been reported for nonsplinted restorations compared with splinted restorations.[31] Inherent inaccuracies cause preload stresses because of component misfit (crown-abutment and abutment-implant). When several adjacent implants are restored when crowns are splinted, the moments that

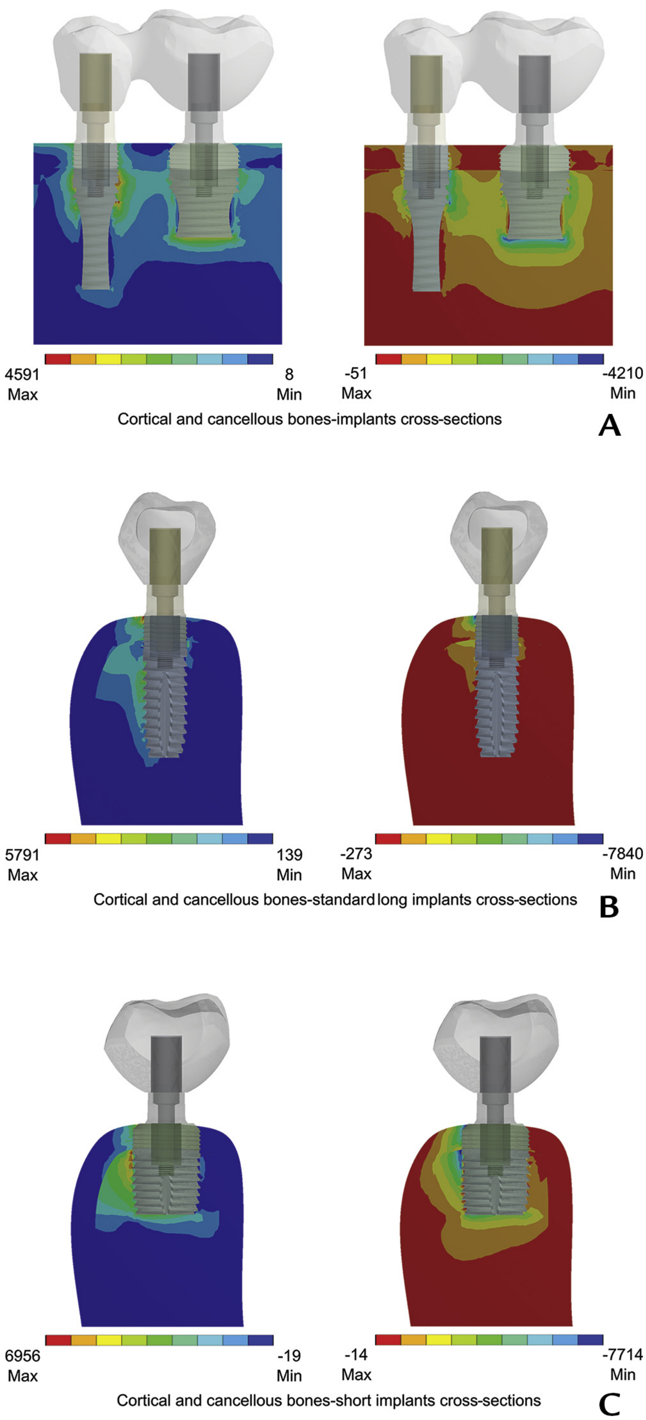

Figure 5. Minimum and maximum principal strains (με) in bone-implant cross-section views on splinted crowns under oblique load for most successful design (MIH) (Values for MSC and MIC models given in Fig. 7). A, Standard and long implants. B, Standard implant. C, Short implant. MIH, model internal hexagonal. MIC, model internal conical; MIH, model internal hexagonal; MSC, model stepped conical.

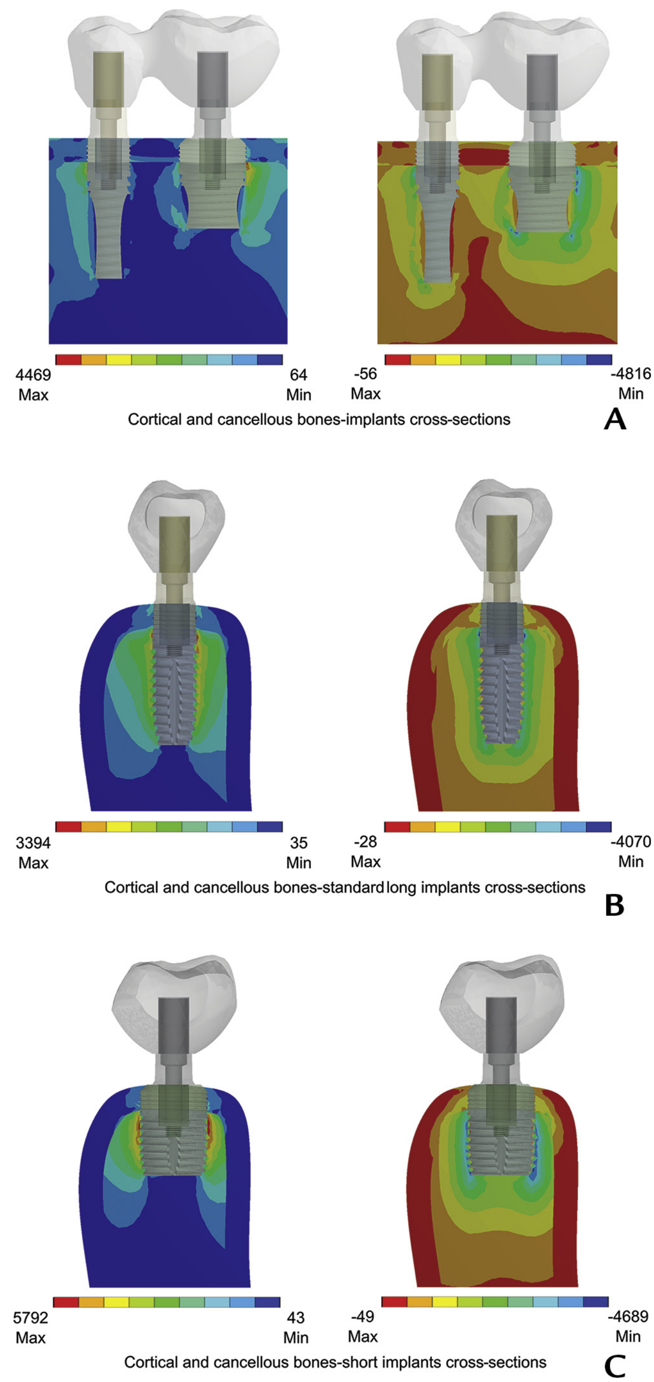

Figure 6. Minimum and maximum principal strains (με) in bone-implant cross-section views on splinted crowns under vertical load for MIH most successful design (Values for MSC and MIC models given in Fig. 7). A, Standard and long implants. B, Standard implant. C, Short implant. MIH, model internal hexagonal. MIC, model internal conical; MIH, model internal hexagonal; MSC, model stepped conical.

increase significantly because of splinting cause increased loads to be transferred to the implants and supporting structures.[31] The load transfer may also explain the disparity of microstrain values on the implant necks.[32] Strain values occurring under the influence of oblique loads were higher than expected under vertical loading. For the boundary

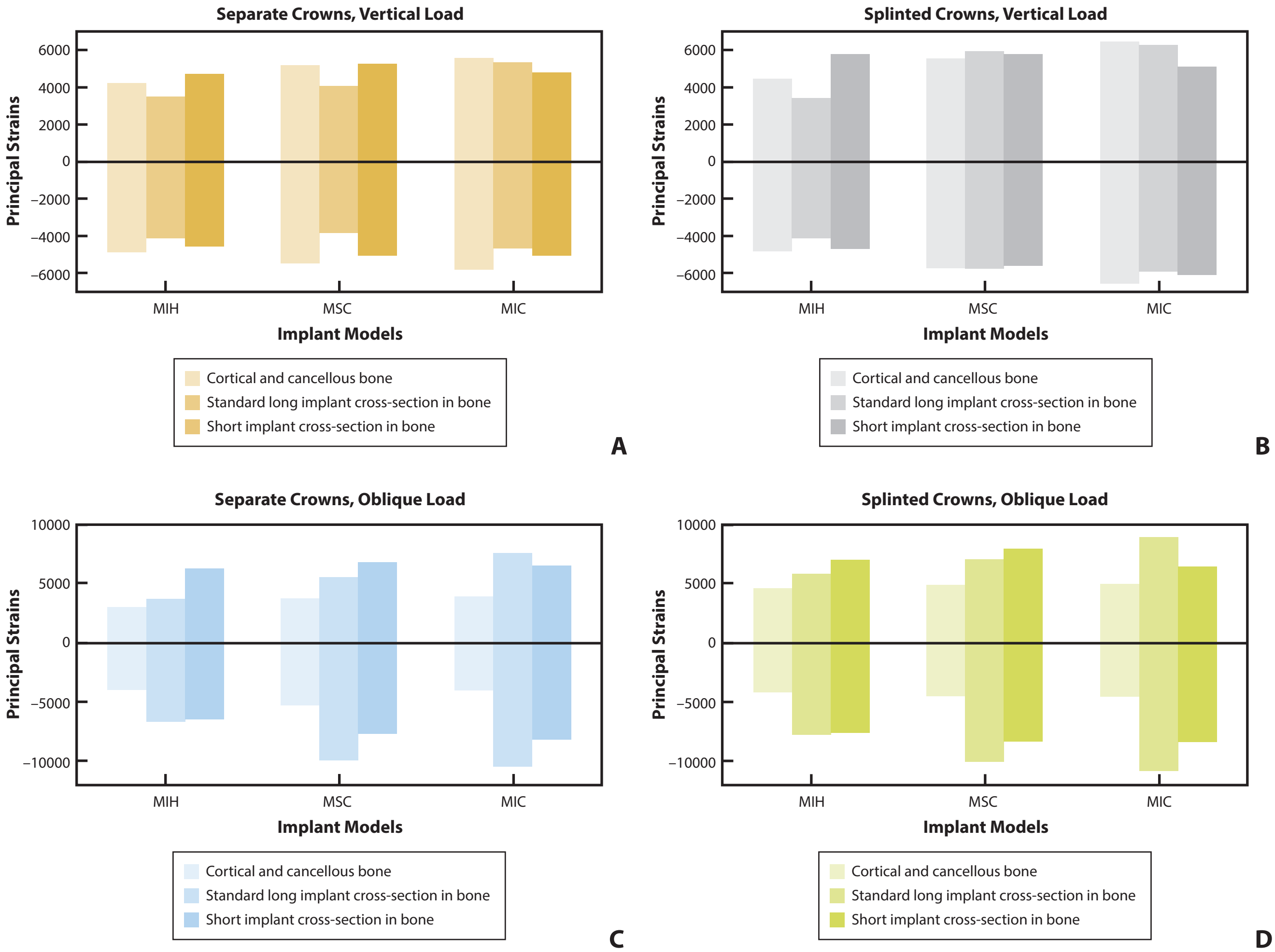

Figure 7. Minimum and maximum principal strains (με) in implant cross-sections in cortical and cancellous bones for different loading conditions. A, Separate crowns under vertical load. B, Splinted crowns under vertical load. C, Separate crowns under oblique load. D, Splinted crowns under oblique load. MIC, model internal conical; MIH, model internal hexagonal; MSC, model stepped conical.

conditions where an oblique load was applied to splinted crowns, the order of minimum principal strain values obtained from the models in long and short implant-bone interfaces was MIH<MSC<MIC (Fig. 7D). Therefore, the separate crown may be more successful in terms of avoiding implant damage, with lower strain than the splinted crown for adjacent long and short implants, especially for MSC and MIC.

In all models, a standard long implant in a splinted prosthesis subjected to oblique forces resulted in high stresses in the surrounding bone. However, the stress to the short implant decreased with splinted prostheses in the MIH model. In the splinted prosthetic design for MIH, MSC, and MIC, the longer implant was exposed to more stress. Toniollo et al,[16] in a similar study, reported that stress on the bone around short implants was reduced with a splinted prosthesis. Moreover, the stress on the surrounding bone next to the tooth also decreased. However, splinted prostheses have been reported to have significantly higher stresses on standard implants compared with those of the nonsplinted groups.[16] In the present study, similar results were found only in the MIH model, in which the stress on the short implant decreased in the splinted prosthesis and the stress on the standard implant increased. However, in other models (MSC and MIC), the load on both the short implant and the standard implant increased in the splinted prostheses. The focus of the present study was to determine how different geometric shapes of implants and abutments can affect stress.

Lemos et al[17] evaluated the stress on implants of the same diameter and different lengths placed adjacent, corresponding to 2 premolars and 1 molar tooth. They concluded that, in splinted prostheses, the stress from the implant and abutment in the molar region decreased and that better stress distribution was achieved compared with nonsplinted prostheses. Reducing the length of the implants, however, did not affect the stress distribution. They attributed the similar stress in standard lengths and shorter implants to a small difference in length between the implant abutment connection used and the implants. Additionally, they recommended that other studies be conducted using shorter implants. However, Lee et al[22] reported that implant length was more crucial in reducing bone stress and enhancing the stability of the implant-abutment complex than implant diameter.

A recent systematic review and meta-analysis reported that splinted and nonsplinted implant restorations had similar marginal bone loss and prosthetic complications but that implant failure may be reduced in splinted restorations.[18] However, implants and abutments of different geometric shapes were not compared in their review. The combination of short and standard implants has no biomechanical advantage, but splinting short implants is an appropriate treatment option.[19] Another study concluded that there was no difference in crestal bone loss when adjacent implants were restored splinted or nonsplinted.[20]

The present study suggests that the most important criterion for implant performance was the shape of the abutment-implant contact area. The smaller the contact area, the greater the strain. The most successful design was MIH because the contact area was the largest; the MSC and MIC were less successful. When the misfit increased, a significant increase in stress concentration was observed in all structures (framework, porcelain veneer, retention screw, and peri-implant bone).[33] A statistically significant positive correlation was found between misfit and stress distribution, and the group with the lowest misfit had the lowest mean strain values.[34] The presence of unilateral angular misfit in a single implant-supported prosthesis increased the von Mises stresses in the implant and the screw.[35] The internal hexagonal geometric feature and concave curves on the junction surfaces of the abutment used in the MIH design with the implant led to less stress at the implant-abutment junction. Although the MSC model was conical, the step in this model was an advantage over the MIC model because it created a wider connection area. Practical clinical considerations from the results of the present study include the importance of an optimal and stable implant-abutment connection, affecting the life of the implant because the stress is reduced. Also, when different lengths of implants are placed close to each other, making separate crowns is recommended. Future studies should evaluate additional implant types and sizes and abutments with splinted and nonsplinted superstructures in the fully edentulous mandible. Keeping the abutment connections the same and examining the effect of pitch, self-tapping features, and spiral numbers may be the subject of an additional study.

CONCLUSIONS

Based on the findings of this finite element study, the following conclusions were drawn:

1. Abutment design was the most critical component among metal implant components.
2. Oblique loads have more moment effect than vertical loads, and the moment effect increases as the angle between the direction of the oblique load and the implant axis increases.
3. If a standard implant and a short implant are placed adjacent and restored with splinted crowns, the implants, abutments, and screws may be damaged in the MSC and MIC models; therefore, adjacent splinted implants should be of similar size.
4. If there is a difference between the lengths of the adjacent splinted implants, in the MIH model, where the implant-abutment connection is perfect, the best results were observed so it can be reported that the perfect fit of the implant-abutment junction reduces stress.

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